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Temporal and Spatial Variability of Sea Surface Temperature within Indonesian Regions Revealed by Satellite Data

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Abstract

To understand variability of sea surface temperature (SST) within the northern (Malacca Strait, South China Sea, Sulawesi Sea, Pacific Ocean of North Papua) middle (Java Sea, Makassar Strait, Molucca Sea, Banda Sea) and southern (Indian Ocean of West Sumatera, South Java-Nusa Tenggara, Arafura Sea) regions of the Indonesian seas, a series of the SST satellite data derived from NOAA-AVHRR Pathfinder 5 with 4 km spatial resolution in the period of 1985-2005 and MODIS data of Level 3 with 9 km spatial resolution in the period of 2000-2005 were collected. The observation results show that the SST within the Indonesian seas has increased though it was annually fluctuated. The SST changes within the Indonesian seas show geographical variability as response to the global, regional and local environmental changes i.e., in the Indian Ocean, SST change was strongly affected by the upwelling occurrences stimulated by the dynamics of the ENSO, while in the Makassar Strait it was influenced by the Indonesian Through Flow and in the South China Sea, the Malacca Strait, the Pacific Sea of the north Papua, the Sulawesi Sea, the Molluca Sea, the Banda Sea and the Arafura Sea they were influenced by the environmental change of the Pacific Ocean as response to the ENSO dynamics.

Key words : *Temporal and Spatial Variability of sea surface temperature (SST), Indonesian regions, satellite data*

1. Introduction

Indonesia is stretching roughly from 6 °N to 10 °S and from 95 °E to 142 °E and occupies a central position of Indo-Pacific, creating permeable barriers between the Pacific and Indian Oceans and the Asian and Australian Continents. It has more than 17,500 islands and coastline in excess of 80,000 km. As the world's largest archipelago, Indonesia is positioned in a strategic location with respect to global ocean circulation patterns. The dynamic nature of the archipelagic seas shows the interaction with the Pacific and Indian Oceans and monsoonal climate, and it may explain the high marine biodiversity of the region to a great extent. Since the climate of the archipelago is under the influence of the Asian-Australian monsoon system, the climate exerts a major influence on the large-scale circulation pattern of intra-archipelagic seas and it plays a significant role in the production of the coastal and marine ecosystems.

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The Indonesian seas strategically situated between the Pacific Ocean on the north and the Indian Ocean on the south, and acts as both a frictional barrier and the link between the two oceans. The flow from the Pacific Ocean to the Indian Ocean (the Indonesian Throughflow; ITF) gives a significant effect to global ocean circulation and to global climate. The tropical regions of the world's oceans are recognized as having major influences on the global atmosphere, and the tropical west Pacific and east Indian Oceans are recognized as the spawning grounds for many important climatic events such as a periodic El Nino and Southern Oscillation (ENSO) events. A number of authors[1)] (e.g., Potemra, 2006) have pointed out that the water properties of the west Pacific and east Indian Oceans are strongly influenced by the Indonesian Throughflow, and that the throughflow is a carrier of heat from the warm water region of the west Pacific to the Indian Ocean. This heat transfer influences the extent of the warm water region of the west Pacific, which in turn relates to the occurrence and severity of ENSO events. Since small anomalies in the sea surface temperature can give large climatological effects, the significant inter-annual variations of the throughflow probably contribute to the aperiodicity of ENSO events and other climate features [2)].

From the view point of the latitude distribution, the environment of the Indonesian Seas can be divided into three regions; the northern part represented by the South China Sea and the coastal area of the Northern Sulawesi and Papua, the middle part represented by the Malacca Strait, the Java Sea, the Maccassar Strait, the Molucca Sea and the Banda Sea, and the southern part represented by the Indian Ocean of the coastal area of the Western Sumatera, Java-Bali-Nusa Tenggara and Arafura Sea. As the largest tropical ocean archipelago, the SST variability within the region is affected by the global recirculation influenced by two dominant oceans surrounding the Indonesian archipelago i.e. the Pacific and Indian Oceans, and it is affected regionally by the local and regional environmental changes derived by the monsoonal system. Studies on the Indonesian seas, particularly focusing on the ocean circulation such as the Indonesian Throughflow have been conducted by some researchers and studies on the Ekman Mass and Heat Transport and the impact of the ENSO on the environment of the Indonesian Sea have also been conducted[3,4,5,6,7]. However, the study of the SST variability and its temporal variation is still limited, particularly in relation to the ocean environment within the region of the seas.

2. Method

A series of the mean monthly and annual SST data of the Indonesian seas (Fig.1) derived from NOAA-AVHRR Pathfinder 5 Level 3 Standard Map Image (SMI) with spatial resolution of 4 km `were collected from NASA[8] (http://poet.jpl. nasa.gov/ for the period of 1985 to 2005). While for MODIS data of Level 3 with spatial resolution 9 km was collected for the period of 2000 to 2005[9] (http://disc.sci.gsfc. nasa.gov/ giovanni/). The data was downloaded in hdf format and then cropped by using SeaDAS 4.7 software.

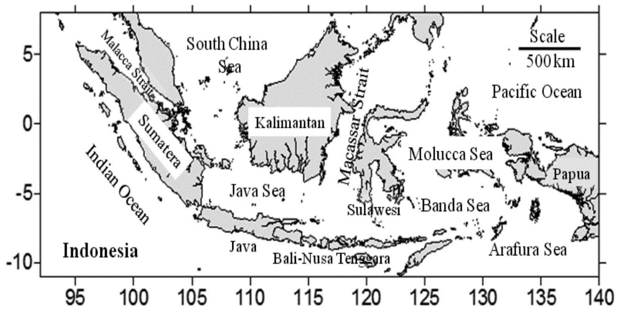

Fig.1. The regions of the Indonesian seas

The ascii data of SST was extracted from the similar source by using the same software and converted into the Excel format. To support the study, a series of wind data of 1985-2005 representing the southern, middle and northern parts of Indonesia was obtained from the Department of Atmospheric Science, University of Wyoming[10] (http:// weather.uwyo.edu/ upperair/sounding. html) and the Global-SST ENSO Index[11] (http://jisao. washington. edu/data/ globalsst enso/) was also collected to understand their influence on the variability of SST within the Indonesian regions, particularly in the region of the seas.

3. Results and Discussion

The Indonesian water is characterized by strong seasonal variation in the upper oceanic circulation, which is influenced by monsoonal winds[12] (Webster et al., 1998). Horizontal distribution of average SST in 2000-2005 is shown in Fig.2. SST within the Indonesian region was varied due to various influence of the local and regional environment as well as the excistence of water mass from the South China Sea and the ITF effect of western Pacific Ocean and ENSO occurences. Low SST water mass is seen to flow into the Java Sea from the South China Sea and on the otherhand warm water from the western Pacific Ocean enters to the Java Sea through the Macassar Strait. In the southern coastal area of Java (Indian Ocean), SST is low arround 27°C that is occured due to the upwelling caused by the Eckman transport as response to the southeasterly wind and spreads out to the southern part of Java[13,14,15,16] (Sachoemar and Yanagi, 2000, 2001, Sachoemar et al. 2002, Susanto et al, 2002). Upwelling within this region develops in transition periode of April-May and reaches the peak level on August-September following stronger wind speed during southeast monsoon [13,14,15,16] (Sachoemar and Yanagi, 2000, 2001, Sachoemar et al. 2002, Susanto et al, 2002). The similar situation was also occurred in the western coastal area of Papua (the Arafura Sea), the upwelling within this region occured during the southeast monsoon which is indicated by widely low SST that is spread out to the western part.

In the Arafura Sea, upwelling and downwelling occur alternately in one year according to the season [17,18] (Wyrtki , 1961 and P3SDPL, 2011). At one season (e,g. southeast monsoon) upwelling occurs and the next season (northwest monsoon), downwelling occurs[17,18] (Wyrtki , 1961 and P3SDPL, 2011). While the upwelling occurence in the southern coastal area of South Sulawesi as seen in Fig.2 seems to be affected by water circulation. The surface current is often changed within this region which is affected by the wind monsoon. During the southeast monsoon, the water masses from the Flores Sea meet with water mass from the Makassar Strait (ITF) and flow together to the Java Sea. In the northwest monsoon, water mass from the Java Sea meets with the coming out water mass of the Makassar Strait and flows along the direction of the Flores Sea. This circulation and wind monsoon seem to be the main factor affecting the upwelling mechanism in the southern coastal area of the South Sulawesi region.

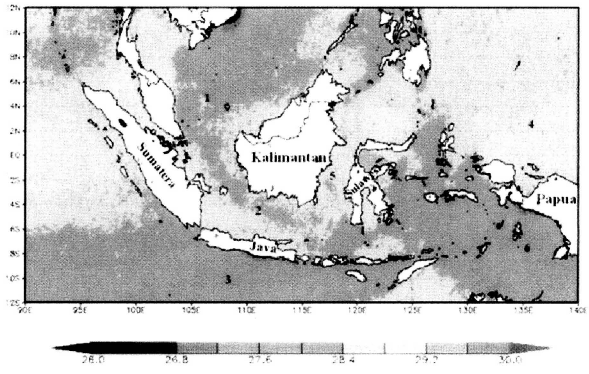

Fig.2. Spatial variability of SST (°C) within the Indonesian regions during the period of 2000-2005 derived by MODIS satellite data (http://disc.sci.gsfc.nasa.gov/giovanni/). South China Sea (1), Java Sea (2), Indian Ocean (3), Pacific Ocean (4), Macassar Strait (5) and Arafura Sea (6).

Maean annual SST within the Indonesian regions vary during the period of 1985-2005 (Fig.3 above). In general, SST in the northern part of the Indonesian region (the South China Sea, the northern coastal area of Sulawesi and Papua in the Pacific Ocean) was the highest and SST in the middle part (the Malacca Strait, the Java Sea, the Macassar Strait, the Molucca Sea and the Banda Sea) was followed. On the other hand, SST in the southern part (the western coastal area of West Sumatera, the South Java-Bali-Nusa Tenggara in Indian Ocean and the Arafura Sea) was the lowest among the Indonesian regions. Low temperature within this region occurred predominantly due to the effect of upwelling generated by the Ekman transport associated with the monsoonal system.

The temporal change of the SST in the northern, middle and southern parts of Indonesian waters occurred nearly at the same time as shown in the SST anomaly (Fig.3 below). The years of high SST anomaly in the whole of the Indonesian area occurred during the periods of 1992, 1996 and 1998 with the highest and maximum SST anomaly in 1998, it was well corresponded with the ENSO event as shown in Fig. 4. The remote system of the ENSO in the western Pacific has controlled the SST within the Indonesian Seas. The warm water mass from the warm pool of western Pacific flows to the eastern part and enters to the southern part of the Indonesian water through the Macassar Strait by ITF. While moderated SST in the middle part of the Indonesian water is resulted from the advection of cold water mass from the southern part of Java and the warm water mass from the western Pacific.

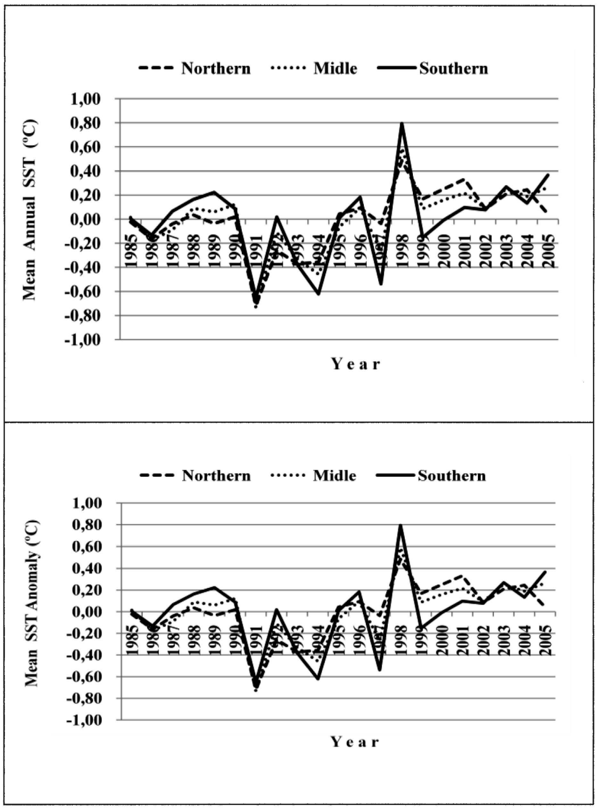

Fig.3. Temporal variability (above) and anomaly of mean annual average SST (below) in the northern, middle and southern part of the Indonesian Seas (during the period of 1985-2005).

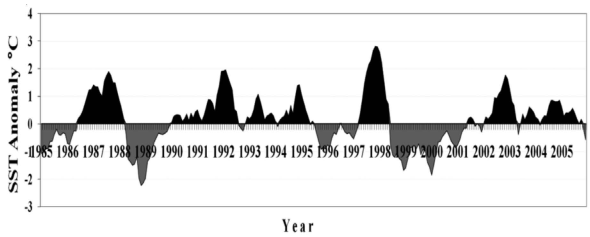

Fig.4. SST anomaly of the ENSO (Nino index) during the period of 1985-2005

The southward strong wind with the maximum velocity in the norhern and middle parts of Indonesia in 1998 is shown in Fig.6, it has driven the current southward and transported the warm water mass from the northern coastal area of Sulawesi (the Pacific Ocean) into the Maccassar

Strait and the Java Sea. It indicated that the Indonesian water mass is influenced by the western Pacific water mass with the combined effect of the ENSO and the wind controlled by atmospheric dynamics. While SST anomaly of the Indonesian waters with significant low SST was occurred 4 times during the period of 1985-2005 as shown in Fig.3, that is, 1991, 1994, 1997 and 1999 with trend increment of SST level. These anomalies are considered predominantly influenced by the upwelling occurrences in the southern coastal area of Java that is controlled by southeasterly wind associated with the monsoonal system and the existence of the global warming effect which is indicated by the same rate of the global SST rise i.e. 0.1°C/year as shown in Fig.6.

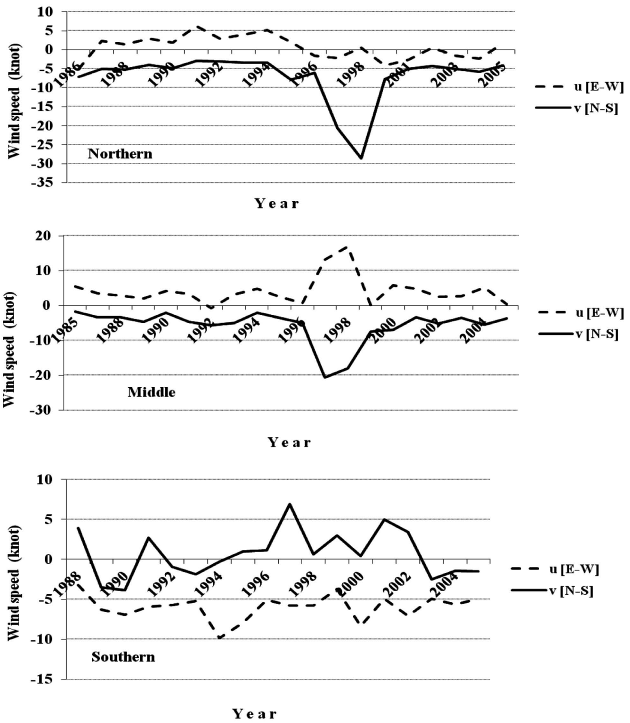

Fig.5. Mean annual average of wind speed (knot) in the northern, middle and southern parts of the Indonesian Seas in the period of 1985-2005. u(-) is east direction, u (+) is west, v(-) is south and v(+) is north.

4. Conclusion

SST variability within the Indonesian Fisheries Management Seas (IFM) varies in the region. The combined effect of the El Nino, ITF and global warming as well as the local, regional and global environment change in association with monsoonal system has a great effect on the variability of the SST among the regions. In the southern part of the Indonesian Seas, the upwelling occurrence due to the Ekman transport is the dominant factor influencing the SST variability, while in the northern and middle parts, the ITF is dominant factor of the SST variability within this region. Further study is necessary to be established to understand more detail of the SST change within the Indonesian region, particularly in relation to the marine productivity.

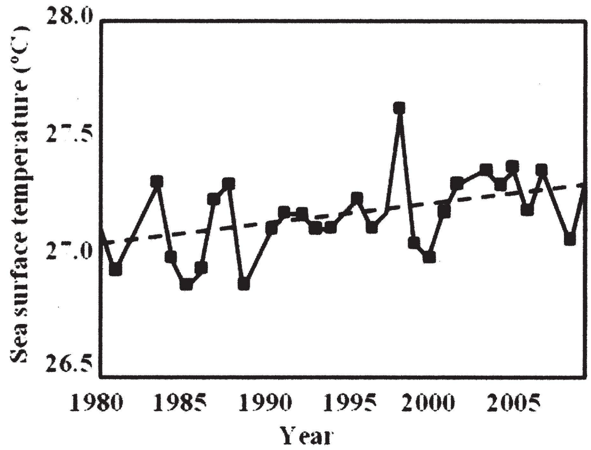

Fig.6. The average tropical sea surface temperature has risen over the past 30 years after [19].

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